DOE/METC/C-96/7221

Title:

Government/Industry Partnership: A Revolutionary Approach in Global Leadership of
Advanced Gas Turbines

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RECEIVED
FEB 13 1996
OSTI

Conference Title:

'96 American Society of Mechanical Engineers/International Gas Turbine Institute
Turbo Exposition

Conference Location:

Birmingham, United Kingdom

Conference Dates:

06/10-06/13/96

Conference Sponsor:

American Society of Mechanical Engineers/International Gas Turbine Institute

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Government/Industry Partnership: A Revolutionary Approach in Global Leadership of Advanced Gas Turbines

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Abstract

The U.S. Department of Energy (DOE) has established a government/industry partnership program to greatly improve the capabilities of U.S. gas turbine technology. A new and challenging program named the Advanced Turbine Systems Program (ATS) has been initiated by DOE. The technical and business objectives of this initiative are to challenge the bounds of high performance capabilities of gas turbines, meet stringent environmental requirements, and produce lower cost electric power and cogeneration steam. This program will also yield greater societal benefits through continued expansion of high skilled U.S. jobs and export of U.S. products world wide.

A progress report on the ATS program pertaining to program status at DOE will be presented and reviewed in this paper. A preliminary design of an industrial advanced turbine system configuration will also be outlined in the paper. The technical challenges; advanced critical technologies incorporation, analytical and experimental solutions, and test results of an advanced gas turbine meeting the DOE goals will be described and discussed.

Background

In July 1993 the U.S. Department of Energy submitted a comprehensive program plan¹ to the United States Congress outlining an ambitious 8-year \$700 million cost-shared program to develop advanced turbine systems for land-based applications. The program is currently in its fourth year, with the objective to complete development of advanced turbine systems by the year 2000 to enable their market introduction early in the next century. Turbines capable of meeting industrial cogeneration and electric utility combined cycle electric power generation market requirements will be developed.

Six gas turbine manufacturers were supported to conduct program definition studies under the first phase of the ATS Program. Allison Engine Company, Asea-Brown Boveri, General Electric Corporation, Solar Turbines, United Technologies Turbo-Power & Marine, and Westinghouse Electric Corporation each developed system configurations and resource requirements².

Under the second phase of the program, five turbine manufacturers were competitively selected to further develop their concepts.

Allison Engine Company, Asea-Brown Boveri, General Electric Corporation, Solar Turbines, and Westinghouse Electric Corporation are currently developing conceptual designs of gas-fired systems along with detailed designs and testing of critical components. Allison Engine Company and Solar Turbines are developing industrial cogeneration systems. Asea-Brown Boveri, General Electric Corporation and Westinghouse Electric Corporation are developing electric utility power generation systems.

In September 1995 the U.S. Department of Energy awarded cost-shared cooperative agreements to four turbine manufacturers that will culminate in the pre-commercial demonstration of one industrial and one utility-scale ATS system. Cooperative agreements have been awarded to: Allison Engine Company and Solar Turbines for industrial-scale and General Electric Corporation and Westinghouse Electric Corporation for electric utility-scale ATS systems.

The Technology Base Development element of the ATS program sponsors generic research that directly supports the major manufacturers' development efforts. The Technology Based Development activities include an industry/university consortium; materials and manufacturing technology development, and cooperative research using available government facilities. In 1995 contracts were awarded, through the Oak Ridge National Laboratory Materials Development Program, to Howmet Corporation and PCC Airfoils to develop improved turbine component castings. Also, through the DOE Oak Ridge Materials Development Program, two projects were awarded to Westinghouse Electric

Corporation and Pratt & Whitney to develop thermal barrier coatings.

Objectives

The ATS program will develop natural-gas-fired systems for electric utility markets and for cogeneration and mechanical drive applications in industrial markets. The goals of the ATS Program are:

- Efficiency -- Greater than 60 percent system efficiency (LHV) on natural gas for large-scale utility turbine systems. Greater than 15 percent improvement in system efficiency for industrial turbines over 1991 vintage technology.
- Environment -- Environmental superiority under full and part load operating conditions without the use of postcombustion controls. NO_x emissions lower than nine parts per million by volume (ppmv) and carbon monoxide and unburned hydrocarbon emissions less than 20 parts per million (ppmv).
- Fuel Flexibility -- Initial ATS systems will be designed for operation on natural gas with adaptability for firing with biomass and coal derived fuels.
- Cost of Power -- Busbar energy costs at 10 percent less than current state-of-the-art (1991 vintage power systems) turbine systems, meeting the same environmental requirements.
- RAM -- Reliability, availability, and maintainability (RAM) equivalent to current state-of-the-art turbine systems.

Status

The Advanced Turbine Systems (ATS) Program is positioned to provide systems

capable of meeting the program objectives by the year 2000. In 1995 the DOE competitively awarded cooperative agreements to four turbine manufacturers to continue development of two industrial, Allison Engine Company and Solar Turbines, and two utility, General Electric Company and Westinghouse Electric Corporation, scale ATS systems.

Each jointly sponsored project consists of two major development phases: Phase* III: Technology Readiness, and Phase IV: Pre-Commercial Demonstration. Currently, only one industrial and one utility scale system manufacturer will receive support from the DOE in Phase IV: Pre-Commercial Demonstration.

Allison Engine Company

The Allison ATS system builds upon Allison's extensive military aviation gas turbine experience. Allison's approach is to develop a core engine capable of providing a series of engines from simple cycle to intercooled/recuperated gas turbines capable of meeting ATS program requirements. Design and performance characteristics of the Allison ATS system are: high firing temperature -- 2400-2600 °F, high pressure ratio -- up to 29:1, dry low NO_x combustion, net system output ranging from 5 to 15MW, and system thermal efficiency of 37-50% (LHV).

Allison's project consists of two phases, Technology Readiness Testing and Pre-Commercial Demonstration, the first of which is a 48 -month, \$73 million cost shared effort. Under the Technology Readiness Phase (Phase III of the ATS Program) DOE is providing \$45 million with Allison providing the remaining \$28 million.

If selected to perform the Pre-Commercial Demonstration, DOE will provide \$3 million with Allison providing the remaining \$6 million.

Solar Turbines

The Solar ATS system builds upon Solar's proven experience in recuperated industrial gas turbine systems. The unique feature of the Solar ATS system is the integration of a highly efficient compact recuperator which provides improved system efficiency and good part load

performance characteristics. Design and performance characteristics of the Solar ATS system are: recuperation, dry low NO_x combustion (9 ppm NO_x), 2200 °F firing temperature, 9:1 pressure ratio, net system output of nominally 10MW, and system thermal efficiency of 45% (LHV).

Solar's project consists of two phases, Technology Readiness Testing and Pre-Commercial Demonstration, the first of which is a 48-month, \$146 million cost shared effort. Under the Technology Readiness Phase (Phase III of the ATS Program) DOE is providing \$65 million with Solar providing the remaining \$80 million. If selected to perform the Pre-Commercial Demonstration, DOE will provide \$3 million with Solar providing the remaining \$17 million.

General Electric Corporation

General Electric Corporations (GE) ATS system is referred to as "H" technology. GE's program with the DOE is jointly developing 50Hz and 60Hz gas turbine

* Phase number refers to phases as defined by ATS program. Phases I and II are completed, or in progress.

combined cycle systems for U.S. and international markets. The most unique feature of the "H" technology is the incorporation of closed-loop steam cooling to enable improved efficiency (1.5 to 2.0 percentage points increase) with no increase in combustor burner temperature. Design and performance characteristics of the GE 7H combined cycle ATS system are: closed-loop steam cooling, 4-stage power turbine, 18-stage compressor, dry low NO_x combustion (9 ppm NO_x), 2600 °F firing temperature, 23:1 pressure ratio, net system output of 400MW, and system thermal efficiency greater than 60% (LHV).

GE's project consists of two phases, Technology Readiness Testing and Pre-Commercial Demonstration, the first of which is a 27-month, \$170 million cost shared effort. Under the Technology Readiness Phase (Phase III of the ATS Program) DOE is providing \$50 million with GE providing the remaining \$120 million. If selected to perform the Pre-Commercial Demonstration, DOE will provide \$70 million with GE providing the remaining \$173 million.

Westinghouse Electric Corporation

The Westinghouse ATS system builds upon the significant improvements achieved with their current "G" technology. The Westinghouse ATS system, like the GE system, incorporates advanced closed-loop cooling to achieve significant efficiency improvements. Design and performance characteristics of the Westinghouse ATS system are: closed-loop cooling, 4-stage power turbine, 17-stage compressor, dry low NO_x combustion (9 ppm NO_x), 2700 °F firing temperature, 25:1 pressure ratio, net

system output of 440MW, and system thermal efficiency greater than 60% (LHV).

The Westinghouse project consists of two phases, Technology Readiness Testing and Pre-Commercial Demonstration, the first of which is a 27-month, \$64 million cost shared effort. Under the Technology Readiness Phase DOE is providing \$38 million with Westinghouse providing the remaining \$26 million. If selected to perform the Pre-Commercial Demonstration, DOE will provide \$81 million with Westinghouse providing the remaining \$121 million.

Generic research in support the major manufactures development efforts is sponsored through the DOE Oak Ridge Operations Office, Materials Development Program and through a cooperative agreement with the South Carolina Energy Research & Development Center (SCERDC).

Materials/Manufacturing for Advanced Turbine Systems

Four projects were initiated in 1995 to develop advanced manufacturing methods and materials for advanced turbine systems. Multi-year development projects were awarded to Howmet Corporation, PCC Airfoils Inc., Pratt & Whitney and Westinghouse Electric Corporation.

Howmet Corporation's project will scale aircraft gas turbine casting technology to land based gas turbine size components. The major objective of the project is to scale single-crystal casting methods to industrial scale turbine blades with acceptable yields at reasonable costs. The project has four technology thrust areas which are: Low

Sulfur Alloys (reduction of sulfur to improve environmental resistance), Casting Process Development (understand relationship between casting process conditions and product quality), Post-Cast Process Development (mold removal, heat treatment, and inspection techniques), and establishment of Casting Defect Tolerance Levels.

The PCC Airfoils, Inc. project will scale aircraft turbine casting technology to land based gas turbine size components. The specific goal of the effort is to define manufacturing methods that will enable single crystal technology to be applied to complex-cored airfoil components for power generation applications. A major emphasis of the PCC is to optimize alloy melt methods to reduce sulfur content in turbine blade alloys to or below 0.5 ppmw.

Two projects were initiated in September 1995 with Pratt & Whitney and Westinghouse Electric Corporation to develop thermal barrier coatings (TBC's) for ATS. The potential for TBC's to provide the necessary insulation as well as oxidation and corrosion resistance will be evaluated.

Advanced Gas Turbine Systems Research

The Advanced Gas Turbine Systems Research (AGTSR) program is a collaborative University-Industry R&D Consortium that is managed and administered by the South Carolina Energy R&D Center. AGTSR is a nationwide consortium dedicated to advancing land-based gas turbine systems for future power generation capability. It directly supports the technology-research arm of the ATS

program and targets industry-defined research needs in the areas of combustion, heat transfer, materials, aerodynamics, controls, alternative fuels, and advanced cycles. Currently there are 78 performing member universities representing 36 states, and six cost-sharing U.S. turbine manufacturers. A total of 31 research projects are currently in process.

An Industrial Advanced Gas Turbine Program

Allison Engine Company, a recipient of the DOE Advanced Turbine Systems development and demonstration cooperative agreement, is developing a family of advanced industrial gas turbines. The advanced technology and critical components base of these gas turbines is derived from ongoing aero-derivative engine development and production engine programs at Allison. The successful technology and components transfer process will continue for the ATS program for industrial engines development and full scale demonstration. These industrial gas turbines incorporate high efficiency, low specific fuel consumption, and high reliability, availability, maintainability and durability.

Diversity of participants and involvement of end users in system design and full scale system tests are important. These inputs ensure overall success of the advanced gas turbine program. End users' participation enhances the value of the final product, and accelerates planned commercialization of a cost competitive power generation system.

Advanced Gas Turbines: A Partnership Program

The advanced gas turbine program represents a true partnership between the federal government and manufacturers. The industry is in a position to incorporate evolutionary improvements in its products, primarily due to business pressures of quick income producing measures. The U.S. already spends a smaller percentage of its gross domestic product on research and development compared to other industrialized nations. Japan, Germany and France allocate a larger share of their gross domestic product to research and development. The advanced gas turbines program represents the future "personnel computers" of the energy world, according to a representative of the Federal Office of Science and Energy³. The program is essential to enable the U.S. industry compete effectively in the global market. The benefits of this program to U.S. taxpayers are protect the high skilled jobs in the U.S. and to enhance net exports.

In addition to the government/industry as partners in this vital program, participation of potential customers is also essential to make the final product successful. A conceptual arrangement of this partnership is presented in Figure 1. The DOE's role is to steer the program in the direction which would maximize the benefits of development and commercialization of the new product to U.S. taxpayers. Allison's role is to produce and commercialize the product, meeting both the DOE and end users' goals. The end users' participation is to ensure that the product to be commercialized is superior to alternative power generation sources.

Engine Development and Demonstration Elements

The engine development and demonstration functions incorporate four distinct elements -- product strategy, advanced technology, market potential, and commercialization. Allison's land based power generation and cogeneration systems are derivatives of its military and commercial aviation engines. The advanced gas turbines utilize current aviation products which are already commercialized or nearing commercialization. This product development and demonstration strategy minimizes incurring major expenditures for component development, producibility, and greatly improves product reliability.

The Department of Defense's (DoD) V22 Osprey and and C130 engines, and the AE2100 advanced turbo-prop and turbo-shaft engines in the SAAB regional aircraft provide the engine core for advanced industrial gas turbine engines. An illustration of these commercial engine products is presented in Figure 2.

The advanced technology for advanced industrial engines is derived from the various military and National Aeronautics and Aerospace Administration programs. The core of the advanced industrial engine is from the T406 program. DoD's Integrated High Performance Turbine Engine Technology Initiative contributed to the development of the hot section of the advanced engine. Figure 3 depicts a pictorial synergy between the existing aviation programs and advanced industrial gas turbine engines.

In military engine development, the end user and specific requirements are defined

and known during the early conceptual design phase. In industrial applications however, end users of advanced industrial engines are known as a potential generic category. Market forecasts form the basis for future market needs in industrial power generation and cogeneration. These generic market projections are used in setting the various requirements of advanced industrial gas turbine engines. The end product is developed to serve the needs of a group of anticipated customers.

An evaluation of potential markets in the power generation, cogeneration, gas compression, and marine and shipboard applications was conducted by an outside consultant⁴. This information was used as a guide in scoping the performance and other requirements for the advanced industrial gas turbine engines. This study also helped in firming up the need for a family of engines to serve the diverse market opportunities evolving between now and the year 2010. An estimate of the potential market for industrial gas turbines in the 3 megawatts (MW) to 15 MW range is provided in Figure 4.

A serious assessment was also made of the new market opportunity in distributed generation in the U.S. and worldwide. This application appears to be of great interest to electric companies and independent power producers. A study is being initiated (through DOE and EPRI's guidance) with an outside consultant, to assess the potential of this new market opportunity. The results of this study will be available for presentation by the time of the IGTI Turbo Expo '96.

End user preferences and understanding of their power generation and cogeneration needs are essential to achieve successful

commercialization. Considerable interactions with potential end users were initiated to help develop the many features of the advanced engines. System configuration, capital cost, life cycle cost, fuel flexibility, and ease of mobility of the power source were among the factors on which end users' views were solicited. These inputs strengthened the belief that industrial engine configurations should be kept as simple cycle or combined cycles to enhance their acceptance. This preference indicates customers' distinct satisfaction with advanced simple cycle/combined cycle modes of operation over other forms.

Customer survey also indicated the importance of an established global distribution, maintenance and repair centers network by engine manufacturers. These factors seem to influence the customers' decision-making process and in the selection of the type of advanced engines for their applications.

Development Engine Configuration

The engine core as indicated earlier, is derived from an aero-derivative T406 engine.

Other components and critical technology from the aircraft programs are added to this core. The advanced industrial engine actually represents a family of engines from a nominal 5 MW to approximately 12 MW, when operated in a simple cycle mode.

A cross section of the development engine meeting the Department of Energy goals is shown in Figure 5. A two shaft advanced industrial engine is selected for development. The engine is primarily a simple cycle configuration, with the capability to operate in a combined cycle mode. The engine is designed to operate at

approximately 1430 °C (2600 °F) rotor inlet temperature, at a pressure ratio of about 30.

Castcool[®] single crystal technology, developed on military programs, is used for the hot section of the gas turbine. The high pressure compressor is derived from the core engine, and modified to represent an industrialized version of an aircraft engine compressor. The combustor design is derived from the low emission combustor developed to meet the emissions requirements in industrial applications. The boost compressor represents improvements made to existing boost compressor in production engines.

Customer Participation in the Development and Demonstration Program

It is necessary to seek and secure end user participation in the development of an advanced industrial gas turbine engine. This interaction enhances the viability and acceptance of the final product in the marketplace. To help achieve this goal, Ipalco Enterprises has joined the development and demonstration program as a partner. This end user is guiding the development of the final product by participating as a member of the steering and oversight group for the project. Additionally, Ipalco is having a survey conducted to facilitate the selection of an optimum host site where the long term testing of the full scale demonstration system will be conducted.

The Electric Power Research Institute (EPRI) has also joined the program to ensure proper testing of the full scale system. EPRI will develop the test program and conduct the monitoring of the long term tests. One key feature incorporated in the

test program is to conduct durability surveillance testing. This process helps identify the critical component/part in achieving the design life of the product. It also outlines the steps necessary to improve the critical part's design in order to obtain satisfactory operation of the system in accordance with the overall goals.

Summary

The advanced industrial gas turbine engine program is destined to provide the right product, using the proper mix of advanced technology. The output is expected to be a successful family of advanced gas turbines to serve the U.S. and global markets. The Department of Energy's concept to develop advanced gas turbine engines is the right concept, and the timing is critical.

The product represents a true partnership between government, industry and customers. The final product will deliver at least 15% higher overall efficiency, will meet 8 ppm NO_x, <20 ppm CO and UHC, and will be at least 10% lower in overall busbar cost. These competitive products will help maintain the technological superiority of the U.S. gas turbine industry. The approach is structured to be successful. The U.S. taxpayers will benefit directly from this investment and partnership through increased U.S. jobs, and improved net exports.

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4. ATS Market Study -- EDR 17249. Prepared for the Department of Energy, Morgantown Energy Technology Center. Final Topical Report, February 1995

PARTNERSHIP PROGRAM

Figure 1

VS04-2117

ALLISON T406 / AE / ATS ENGINE FAMILY

UNCLASSIFIED
Figure 2

VS04-2478

3-11 MW INDUSTRIAL GAS TURBINE MARKET FORECAST

Figure 3

VS04-2124

TECHNOLOGIES DEVELOPED UNDER IHPTET, NASA
AST AND INTERNALLY WILL TRANSITION TO
GROWTH T406 AND ATS

UNCLASSIFIED
Figure 4

VS-1-100

ATS ENGINE CROSS SECTION

Figure 5

VS-1-110